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# PERFORMANCE PARAMETERS OF THE X-20 DYNA-SOAR PROTOTYPE FULL PRESSURE ASSEMBLY

*LEE C. ROCK*

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BIOMEDICAL LABORATORY
AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Project No. 6301, Task No. 630104

## NOTICES



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## FOREWORD

This report covers the work accomplished in testing the X-20 Dyna-Soar first prototype High Altitude Full Pressure Assembly under Project 6301, "Aerospace Systems Personnel Protection," Task 630104, "Space Protective Garments," as requested by the Aeronautical Systems Division project office. The testing was accomplished during the period beginning 27 September 1962 and continuing through 3 January 1963. On 30 April 1963 a $CO_2$ accumulation test was accomplished. The protective assembly was fabricated by the David Clark Company under Contract AF 33(657)-7897. Testing of the assembly was accomplished in the various specialized facilities of the 6570th Aerospace Medical Research Laboratories. In this area much valuable assistance was received from Mr. Milton Alexander, Anthropology Branch, Mr. Fritz Klemm, Biothermal Branch, Dr. Cletus J. Muick, Environmental Stress Branch, and Dr. Charles R. Nixon, Biological Acoustics Branch. In addition, Mr. Kent Gillespie and Mr. Jim Kramer from the Personal Equipment Branch of the Aeronautical Systems Division, Directorate of Operational Support Engineering, assisted throughout the test series. TSgt Eugene Fritz scheduled the tests and accumulated the test data. Test subjects were TSgt Eugene Fritz, Mr. Michael Colgan, and Mr. Joseph Vetrick.

Motion pictures of the parachute harness drop test and the second run of the flotation test are recorded on film, catalog no. USAF 35541, maintained by the 1350th Motion Picture Squadron, Wright-Patterson Air Force Base, Ohio.

## ABSTRACT

The X-20 Dyna-Soar Prototype Model Full Pressure Assembly was subjected to a series of tests to determine the performance parameters of the suit. These tests include those considered by Aerospace Medical Research Laboratories to be the basic standard performance tests for anthropomorphous protective assemblies in addition to those particularly requested by the Dyna-Soar Project Office. This report presents all the data obtained from the various tests and is presented as indicative of performance parameters only. No attempt has been made to equate the assembly performance with the X-20 Dyna-Soar mission and vehicle performance or with the performance of any other anthropomorphous protective assembly.


## PUBLICATION REVIEW

This technical documentary report is approved.

Wayne H. McCandless

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory

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Dyna-Soar Prototype Pressure Suit

## DESCRIPTION OF THE FULL PRESSURE SUIT

The helmet (fig. 1) is identified as Dyna-Soar Dome No. 1, P/N ACS-362, Serial No. 169, manufactured by David Clark Co., Inc. It is constructed of molded fiberglass, is generally spherical in shape, and has a diameter of approximately 14 inches. The visor operates mechanically and recesses into the shell when open. Internal suit pressure seals the visor. An inflatable positive sealing bladder (fig. 2) is laced to the inner periphery of the shell visor opening. The acrylic plastic visor has reinforced edges of fiberglass and metal and includes a rubber edging for sealing. The helmet attaches to the torso by a neck ring of approximately 9-3/4 inches average diameter.

The buffet helmet (fig. 3) is composed of four separate parts of firm foam rubber covered with nylon mesh. These four parts are connected to each other with Velcro tabs at the top and to four places around the periphary. The ear defenders have an inner padding of soft foam with removable, smooth plastic covers. The communication equipment, including cord and U-174/U plug-in microphone element, M 101/AIC, are incorporated into the two side sections. An interphone connection, U-179/U and a U-173/U, is located at the top where the two parts separate. Included also is a chamois lined, twill-backed, adjustable chin strap. The quarterly spacing of padding down to the ear-circumference area allows air circulation and cooling in addition to size adjustment.

The gloves have a neoprene bladder, restrained by leather palms and fingers with link net covered by Helanca fabric over the back of the knuckles for ease in flexure, see figure 4. Aluminized fabric covers the remaining parts of the glove to wrist ring. There is a diagonal metal palm restraint with an adjustable strap over the back of the hand. A 4-inch cuff, which extends from the wrist point to the "O" ring sealed wrist rings, attaches to the torso arm section.

The torso section of the pressure assembly (figs. 5 and 6) is identified as A/P 22S-2 (9), Flying Outfit, High Altitude, Full Pressure, Manufacturer, David Clark Co., P/N S-930, size: medium-regular. The torso is constructed of the same materials and utilizes the same fabrication techniques or procedures used for the A/P 22S-2 full pressure suit (Specification MIL-C-27649, Coveralls, High Altitude CSK-6/P22S-2, dated 15 November 1961) with the following changes:

a. The neck ring is supported by a fiberglass neck yoke. This is combined with the redesign or method of assembly of the link net in the shoulder-neck area to eliminate the necessity for a helmet tie-down cord and associated hardware. The yoke is in two sections so as to accommodate the gusset between the shoulders. The gusset is required to provide head space in donning (figs. 7 and 8).

b. Between the outer nylon layer and the link net restraint layer, a 1/4-inch layer of foam rubber is added for thermal insulation.

c. The assembly vent system differs from the A/P 22S-2 system in that the breathing air is carried through the tubes to the open helmet and the return air washes over the body to the helmet and is released through tubes from the helmet to the waist outlet port (fig. 9).

d. The only marquisette in the X-20 Dyna-Soar pressure suit torso construction is around the relief pressure-sealing zipper and the ventilating system opening.

Footlets of nylon cloth attach to the torso by zipper and cover the neoprene rubber feet, which are a part of the torso assembly. Figure 10 shows the neoprene foot, the nylon footlet, and the cord adjustment for sizing.

The shoes are Hyde athletic shoes, approximately 11-1/2 inches high with 12 inches of lacings in the inner leather part (fig. 11). The lacings are backed by a leather tongue padded with foam. The sole is formed of hard sponge rubber with a 1/2-inch rise for the heel. The aluminized reflective cover is attached at the edge of the sole and has a heavy-duty zipper from the end of the toe to the top of the boot, just over the lacings of the inner leather boot. The reflective thermal cover is a composite of three layers, an inner nylon lining; a layer of foam rubber, approximately 1/4-inch thick; and an outer layer of aluminized cloth.

The coverall for the torso section is aluminum-coated orlon fabric with a parachute harness and a flotation vest as integral parts. The flotation vest is actuated by small 28-gram cartridge-type $CO_2$ bottle. The coverall attaches to the torso section with zippers at the wrists and ankles. Figure 12 shows the $CO_2$ actuating device with the trigger in the fired position. Figures 13 and 14 show the parachute harness and flotation vest.

## DONNING PROCEDURES

The suit assembly is worn over two-piece long underwear and heavy socks. The subject next dons the torso assembly with the back neck zipper open and the half yoke removed. He puts each foot into the appropriate leg section through the opening made by the pressure sealing zipper. He gradually works the assembly up to just above his knees while seated. With the waist side zippers open, he stands and eases the suit up past his hips. He then seats himself, pulls the nylon footlets on over the neoprene foot bladder, and zips them in place. He inserts his arms in the sleeves of the torso, while bending forward with his head down, then raises his head up through the top of the torso and through the neck ring. This maneuver requires an assistant for execution and utilizes the opening provided in the back neck gusset by removing the back neck yoke. The vent is now attached to prevent the subject from overheating. All necessary torso sizing adjustments are made at this point. The back neck yoke is installed and all zippers closed. The coverall is donned next. Care must be exercised to assure proper positioning of the inner parachute harness. The subject closes the zippers at the wrists and ankles, which attach the coverall to the torso assembly, and closes the front zipper. He puts on the shoes, laces, and zips them. He then dons the helmet, and the neck rings are mated and locked. The buffet helmet is put on through the visor opening and the chin strap snapped. He eases the gloves over his fingers, from which all rings have been removed. The wrist rings are mated and locked. This procedure is reversed for removal of the assembly.

Figure 1. The Helmet

Figure 2. The Helmet Visor Sealing Bladder

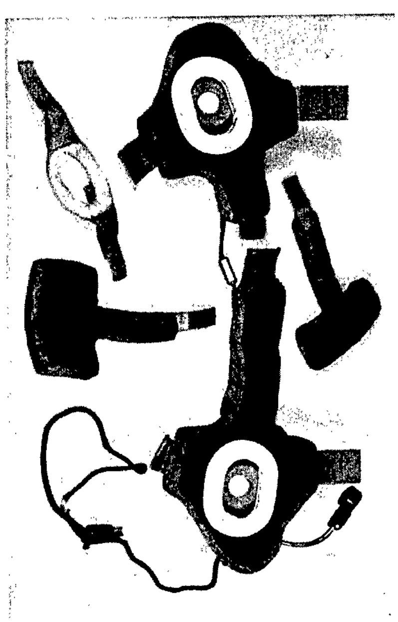


Figure 3. The Buffet Helmet

Figure 4. The Gloves

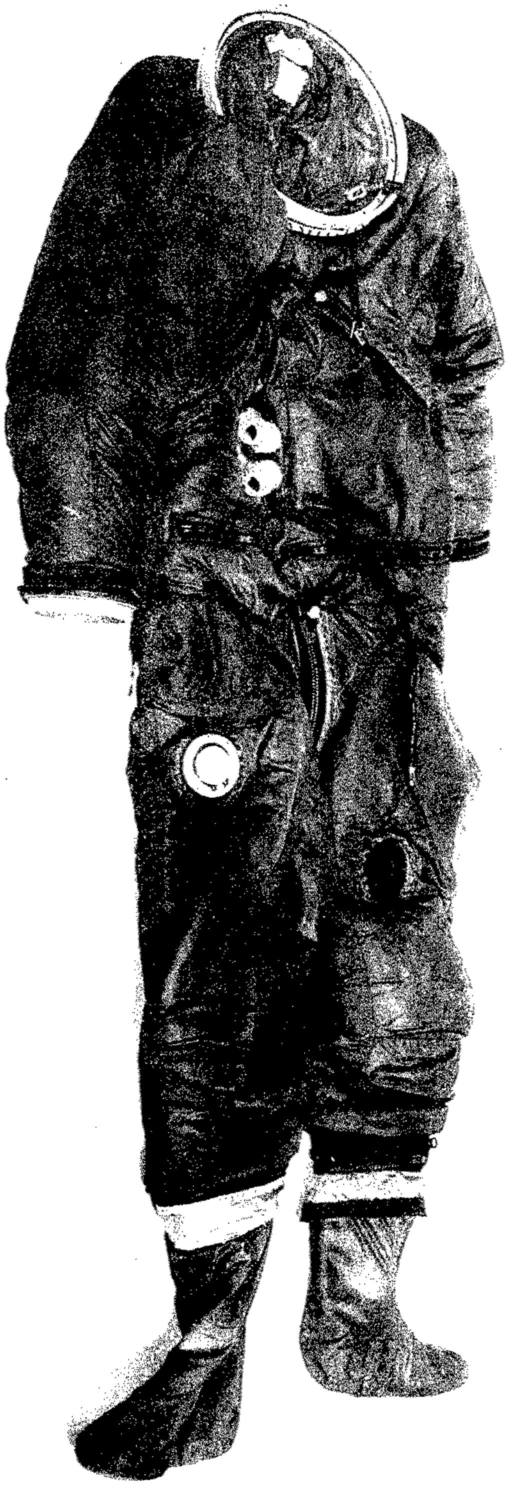
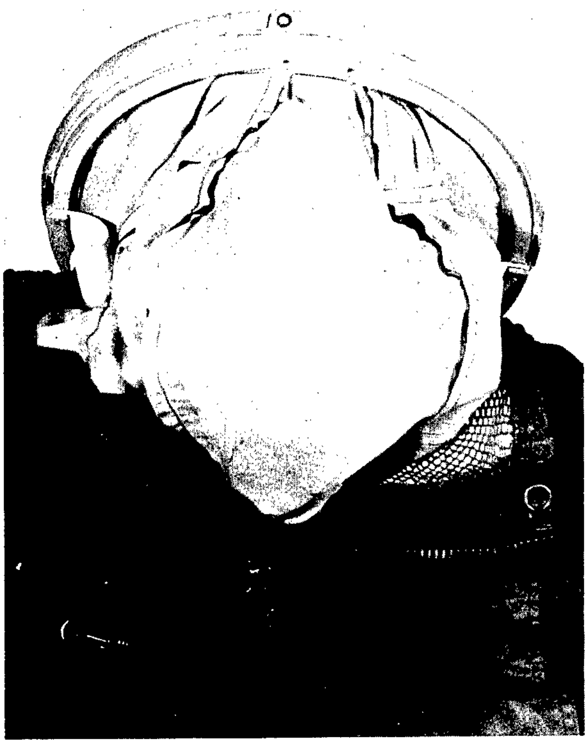


Figure 5. The Torso Section (Front)

Figure 6. The Torso Section (Back)



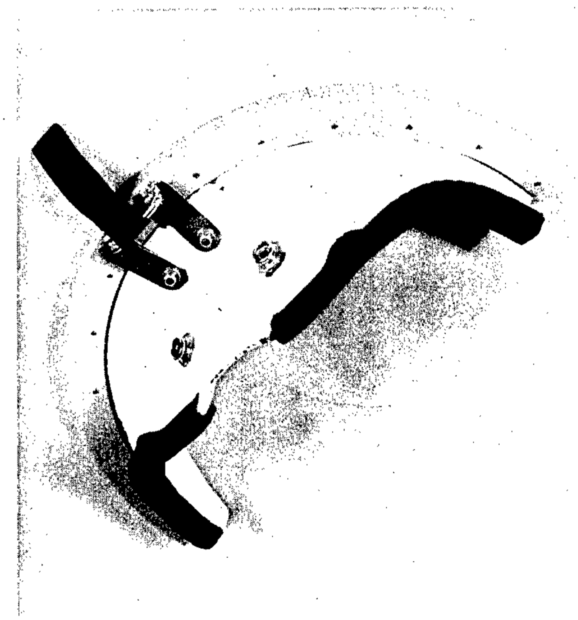


Figure 7. (Upper Left)
The Torso Neck Gusset

Figure 8. (Upper Right)
The Torso Neck Ring Back Support

Figure 9. (Lower Right)
Torso Ventilation Ports

Figure 10. Footlet and Foot Bladder. Note the cord adjustment for sizing just above the zipper.

Figure 11. The Shoes

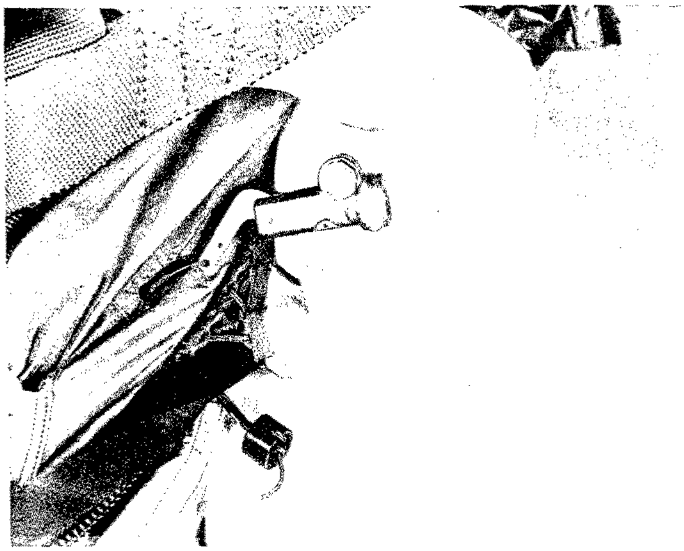


Figure 12. The Flotation Triggering Mechanism

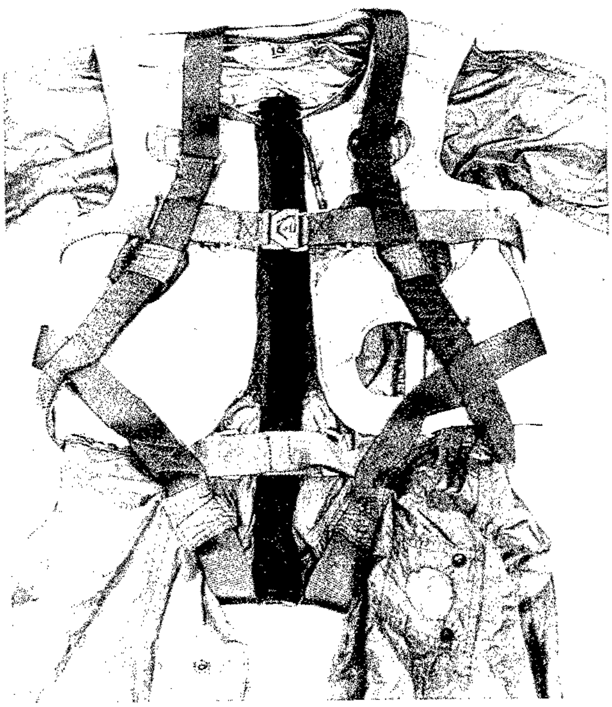


Figure 13. The Coverall
(Inside-Out, Front)

Figure 14. The Coverall
(Inside-Out, Back)

## SEQUENCE OF TESTS

The actual order in which the suit tests were performed is indicated below in table 1. However, the tests are discussed in the text in the manner the author considered most logical for presentation of the results.

TABLE 1

SEQUENCE OF TESTS

| TEST | SUIT TIME hrs. |
|---|---|
| Flotation | 1.5 |
| Inspection and Weight | N/A |
| Functional Arm Reach | 4.0 |
| Work Space | 1.0 |
| Leak Test | 6.0 |
| Inflation Increment | 2.0 |
| Biothermal | 1.5 |
| Biothermal | 1.5 |
| Biothermal | 3.0 |
| Back Pressure | 1.0 |
| Inflation Increment | 1.0 |
| Inflation Increment | 1.0 |
| Biothermal | 3.0 |
| Biothermal | 3.0 |
| Biothermal | 1.5 |
| Biothermal | 2.5 |
| Biothermal | 1.5 |
| Biothermal | 1.5 |
| Biothermal | 1.25 |
| Biothermal | 1.50 |
| Biothermal | 1.50 |
| Biothermal | 1.50 |
| Biothermal | 2.75 |
| Biothermal | 4.00 |
| Biothermal | 4.50 |
| Vision | 3.00 |
| Biothermal | 4.50 |
| Acoustical | 4.00 |
| Biothermal | 4.50 |
| Flotation | 2.00 |
| Biothermal | 1.50 |
| Parachute Drop | 3.00 |
| Altitude Chamber Flight | 0.50 |
| Back Pressure Test | 2.00 |
| Back Pressure Test | 1.00 |
| $CO_2$ Accumulation | 1.00 |

## SUBJECT SELECTION AND SIZING

Three subjects were selected and measured in accordance with the Eight-Size Height-Weight standard. The measurements are shown in table 2. Although the protective assemblies will be tailored to the individuals who will wear them, for evaluation purposes the X-20 (Dyna-Soar) model was built to the medium-regular size of the Eight-Size Height-Weight Standard.*

## INFLATION INCREMENTS

The amount of ballooning or "growth" of a full pressure suit due to inflation is critical, having not only a profound effect upon the mobility, but also the comfort of the wearer. If the expansion in the torso section is excessive, the helmet will rise, causing a change in the field of vision and decreasing head mobility and comfort. Limiting the helmet rise is possible by using a tie-down or by special design of the restraint layer. Other growth problems in pressure suits are rise of the arm scye area and distention of the crotch. These points of discomfort become intolerable after long periods of wear. Excessive growth also affects the working area of the suited man by increasing the ingress and egress openings, the size of the restraint harness, etc. Full pressure suit growth is determined by taking measurements at the same points when the subject is wearing a suit inflated to 0.25 psi (vent pressure), 3.5 psi, and 5 psi. The description of the measurements for inflation increments are as follows:

Axillary Chest Circumference: The anterior scye points are marked on the suit. When the tape is in place the level of the tape in back is marked.

Measured Waist Circumference: The suit is marked one-half distance between the right scye seam and the groin seam. The tape is positioned and the level of the tape in the back is marked.

Axillary Arm Circumference: The anterior upper arm of suit is marked at anterior scye level, perpendicular to long axis of the arm.

Measured Forearm Circumference: The suit is marked one-half distance between anterior elbow crease and top of pressure glove ring.

Measured Thigh Circumference: The suit is marked on the top of the lower leg (thigh and lower leg at 90°) above popliteal crease.

Measured Calf Circumference: The suit is marked at a point 4 inches distal to the popliteal crease.

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* Emanuel, Irvin, and Milton Alexander, Wright Air Development Center TR 56-365 "A Height-Weight Sizing System for Flight Clothing," April 1959.

TABLE 2

TEST SUBJECT ANTHROPOMETRY VS
EIGHT-SIZE HEIGHT-WEIGHT MEASUREMENT STANDARD
FOR MEDIUM-REGULAR SIZE

| MEASUREMENTS | EIGHT H-W SIZE MED REG | Test Subjects A | B | C |
|---|---|---|---|---|
| Height | 64.50 - 69.00 | 67.45 | 66.95 | 67.70 |
| Weight | 150 - 174 | 154.50 | 146.00 | 171.25 |
| Chest Circ | 36.50 - 41.00 | 38.00 | 36.00 | 39.20 |
| Waist Circ | 29.00 - 34.75 | 32.80 | 31.20 | 34.10 |
| Scye Circ | 35.75 - 39.50 | 17.50 | 16.80 | 18.50 |
| Forearm Circ (f) | 61.50 - 66.75 | 11.10 | 10.90 | 11.80 |
| Biceps Circ (f) | 11.75 - 14.00 | 11.90 | 12.10 | 13.00 |
| Lower Thigh Circ | 15.75 - 1900 | 16.50 | 15.40 | 17.00 |
| Thigh Circ | 20.75 - 24.00 | 21.80 | 21.30 | 22.70 |
| Ankle Circ | 08.25 - 09.50 | 7.90 | 8.60 | 9.10 |
| Calf Circ | 13.25 - 15.50 | 13.60 | 13.50 | 15.70 |
| Elbow Circ | 11.25 - 13.25 | 11.30 | 11.50 | 12.20 |
| Wrist Circ | 06.25 - 07.25 | 6.30 | 6.40 | 7.45 |
| Neck Circ | 14.00 - 15.75 | 14.10 | 14.50 | 14.90 |
| Buttocks Circ | 35.75 - 39.50 | 35.50 | 36.90 | 38.20 |
| Vertical Trunk Circ | 61.50 - 66.75 | 63.00 | 62.80 | 62.70 |
| Crotch Height | 30.25 - 33.75 | 32.70 | 30.75 | 31.70 |
| Sleeve Length | 31.25 - 34.75 | 34.20 | 33.00 | 35.60 |
| Chest Breadth | 11.00 - 12.75 | 12.25 | 12.00 | 13.20 |
| Waist Breadth | 09.75 - 11.50 | 11.05 | 10.45 | 11.60 |
| Chest Depth | 08.25 - 09.75 | 9.50 | 9.00 | 9.40 |
| Waist Depth | 07.00 - 08.75 | 9.15 | 8.30 | 9.00 |
| Hip Breadth | 12.25 - 13.75 | 12.30 | 13.15 | 14.00 |
| Hip Depth | 08.00 - 09.75 | 9.65 | 9.55 | 9.30 |
| Shoulder Circ | 42.75 - 47.50 | 45.00 | 43.20 | 48.00 |

Measured Shoulder Breadth: The suit is marked on the anterior upper arm at the scye level perpendicular to the long axis of the arm. The arms are relaxed, hanging at the side. The maximum diameter is measured.

Measured Elbow-Elbow Breadth Pressed: With elbows fixed to 90° and the upper arms at the side, the arms are pressed to the side with the subject using maximum capability. The maximum diameter of the elbow to elbow area is measured.

Posterior Body Plane-Anterior Knee Area: Subject sits against a board which is perpendicular to the floor. The horizontal distance between the board and the most protruding point of the knee is measured.

Thigh Clearance From The Floor: Subject sits upright. The distance from the floor (thigh and lower leg at 90°) to uppermost point of the right thigh is measured.

The above measurements taken on this pressure suit are shown in table 3. Figure 15 shows the growth of the glove beyond the subject's fingers when the assembly was inflated.

## DEXTERITY TEST

Two attempts were made to determine the dexterity deterioration in the performance of the individual wearing the full assembly. The test in a standard cockpit work space apparatus was not possible for two reasons. The helmet viewing area eliminated 10 of the simulation controls from the subject's field of vision and the subject lost finger tactile sense when the suit was pressurized. A run could have been made using the visible controls and a modified program had the subject been able to feel the controls with his fingers. The gloves on both subjects grew away from the ends of the fingers approximately 1-3/4 inches when inflated to 5 psig. Therefore, no data can be presented which might represent the loss of dexterity due to the effects of the full pressure suit.

## FUNCTIONAL ARM REACH TEST

Through the use of the arm-reach measuring device (fig. 16), the radii of the maximum functional arm-reach envelope could be measured at 15° intervals in each of 12 vertical planes. This permits description of shoulder-arm mobility through 360° in the three right-angle planes. Data was obtained on the volume of the grasping reach envelope in shirt sleeves, suited and unpressurized, and suited and pressurized to 5 psig. From this volume the radius of a sphere of equal volume was computed. The normal comparisons to date have been of the grasping reach envelope volume. However, for some uses the radius of the sphere of equal volume is more descriptive. This data is set forth in table 4.

TABLE 3

X-20 DYNASOAR PRESSURE SUIT
INFLATION INCREMENTS

| PRESSURE | 1/4 psi or 13 mm Hg | 3.5 psi | 5.0 psi | 1/4 psi or 13 mm Hg | 3.5 psi | 5.0 psi | 1/4 psi or 13 mm Hg | 3.5 psi | 5.0 psi |
|---|---|---|---|---|---|---|---|---|---|
| | | A | | | B | | | C | |
| Auxillary Chest Circ | 48.20 | 49.50 | 49.90 | 46.90 | 48.20 | 49.50 | 47.50 | 50.00 | 50.50 |
| Measured Waist Circ | 46.00 | 46.10 | 46.30 | 45.60 | 45.90 | 48.85 | 45.00 | 46.70 | 47.00 |
| Axillary Arm Circ | 18.90 | 19.50 | 20.40 | 17.30 | 19.30 | 20.20 | 16.90 | 18.70 | 20.10 |
| Measured Forearm Circ | 15.30 | 15.90 | 15.90 | 14.75 | 15.40 | 15.50 | 15.30 | 15.70 | 16.20 |
| Measured Thigh Circ | 22.40 | 23.30 | 23.40 | 21.90 | 23.20 | 23.50 | 21.80 | 23.90 | 24.00 |
| Measured Calf Circ | 16.10 | 16.60 | 16.50 | 19.00 | 20.30 | 20.60 | 18.70 | 19.10 | 19.60 |
| Measured Shoulder Breadth | 22.45 | 23.80 | 23.55 | 21.75 | 23.50 | 23.45 | 22.50 | 23.65 | 23.65 |
| Measured Elbow to Elbow Breadth | 24.00 | 25.50 | 25.00 | 20.70 | 24.65 | 25.80 | 22.70 | 24.15 | 24.45 |
| Measured Hip Breadth | 16.05 | 15.60 | 15.55 | 15.65 | 16.00 | 15.60 | 15.55 | 15.85 | 15.25 |
| Posterior Body Plane-Ant Knee Area | 26.10 | 29.10 | 29.00 | 26.05 | 26.35 | 27.70 | 25.10 | 26.45 | 27.15 |
| Thigh Clearance from Floor | 23.87 | 25.25 | 25.65 | 23.75 | 25.85 | 25.55 | 24.45 | 25.60 | 26.20 |
| Fingers Bent | 9.30 | 9.75 | 10.30 | X | X | X | X | X | X |
| Hand Length | 10.55 | 11.05 | 11.15 | X | X | X | X | X | X |
| Helmet Rise | 6.50 | 8.35 | 8.20 | 5.95 | 7.85 | 8.65 | 5.50 | 6.55 | 6.90 |

Figure 15. Glove Growth

Figure 16. Arm Reaching Measuring Device

TABLE 4

X-20 DYNA-SOAR FULL PRESSURE SUIT
FUNCTIONAL ARM-REACH TEST

| | SHIRT SLEEVES | SUITED-UNPRESSURIZED | SUITED-PRESSURIZED 5 psi |
|---|---|---|---|
| VOLUME-Grasping Reach Envelope | 31.94 cu ft | 23.59 cu ft | 11.95 cu ft |
| PERCENT DECREMENT From Shirt Sleeves | — | 26.2% | 62.6% |
| RADIUS OF SPHERE Of Equal Volume | 23.61 inches | 21.32 inches | 17.05 inches |
| PERCENT DECREMENT From Shirt Sleeves | — | 9.7% | 27.8% |

## VISION TESTS

Visor optical characteristics were determined using the visor's inherent refractive power, calculated from radius curvature supplied by the David Clark Company. The inherent power of the visor is -187 D. Critical and noncritical areas of the visor were checked on the Focometer in the eight areas according to MIL-V-27446 (USAF). Point C for the right side is plano -0.04 x 110, left side +0.02-0.06 x 95. Vertical and horizontal prismatic deviations were investigated and found to be within the limits of the specification. Visual inspection under bright illumination revealed a few striations and irregularities due to fabrication of the visor. As a prototype item it was satisfactory for testing purposes. The subject was tested for unaided visual acuity, using a Clason Acuity Meter with the screen set for 6 m letter size--right eye 20/20+, left eye 20/20+, both eyes 20/20+. Unaided visual acuity through the visor was right 20/20, left eye 20/20, and both eyes 20/20.

Field of vision studies were conducted with the subject in the suit unpressurized with the visor up and pressurized, visor closed. In the pressurized condition, the position of the dome relative to the eyes differs significantly from the unpressurized condition. Measurements were made temporally, nasally, and superiorily. The inferior motion field had to be estimated. These measurements are shown in table 5. Figures 17 and 18 show the suited subject in the field of vision test area.

TABLE 5

X-20 DYNA-SOAR FULL PRESSURE SUIT
FIELD OF VISION TEST

| MOTION | FIELDS | EYES FIXED HEAD FIXED R-EYE | EYES FIXED HEAD FIXED L-EYE | EYES MOVING HEAD FIXED | EYES MOVING HEAD MOVING | EYES FIXED HEAD FIXED R-EYE | EYES FIXED HEAD FIXED L-EYE | EYES MOVING HEAD FIXED | EYES MOVING HEAD MOVING |
|---|---|---|---|---|---|---|---|---|---|
| Horizontal | Right | 85 | 55 | 93 | 102 | 73 | 55 | 70 | 108 |
| Horizontal | Left | 52 | 77 | 80 | 100 | 50 | 70 | 75 | 111 |
| Vertical | Superior | 45 | 47 | 50 | 50 | 47 | 44 | 55 | 83 |
| Vertical | Inferior | 50 | 50 | -- | 70 | 50 | 50 | -- | 70 |

*All measurements in degrees of arc.

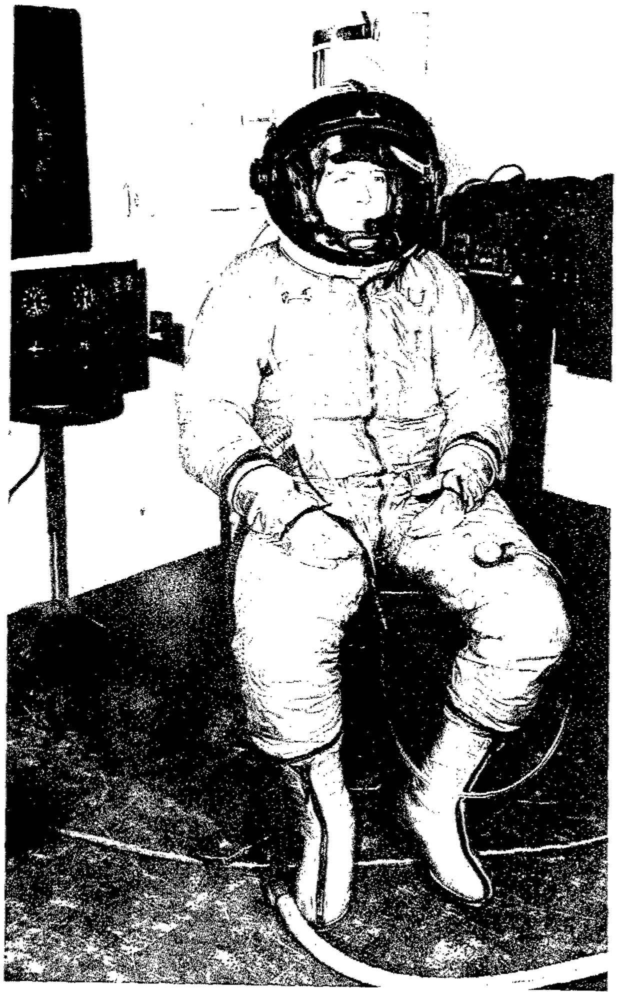


Figure 17 (Left)
Field of Vision (Front View)

Figure 18 (right)
Field of Vision (Back View)

## PARACHUTE HARNESS "DROP" TEST

The parachute harness drop test was performed by having the subject, dressed in the complete full pressure suit assembly, step from a platform. The first platform level was one foot above the hang position. The hang level was lowered in 0.5-foot increments. The data obtained is set forth in table 6. During the test the parachute harness risers interfered with the visor opening mechanism so that the visor could not be opened in the hang position. After the first drop the visor was difficult to close. It was necessary to start the visor travel by hand since the visor did not close when the release mechanism was actuated.

On completion of the test the helmet assembly was examined and the closure latch released. The visor closed properly. The test subject was removed from the assembly and examined by a physician. The subject's chin showed slight swelling on the right lower surface with several superficial abrasions. The longest abrasion was 1/2 inch long.

TABLE 6

X-20 DYNA-SOAR FULL PRESSURE SUIT
PARACHUTE HARNESS "DROP" TEST

| RUN NUMBER | VISOR POSITION | DROP DISTANCE FEET | MAXIMUM G | SUBJECT'S COMMENTS |
|---|---|---|---|---|
| 1 | Open | 1.0 | 6.2 | Chin hit the helmet shell. |
| 2 | Closed | 1.0 | 0.6 | Chin did not hit helmet |
| 3 | Open | 1.5 | 3.1 | Chin hit the helmet. |
| 4 | Closed | 1.5 | 3.1 | Chin did not hit the helmet. |
| 5 | Open | 2.0 | 37.2 | Chin hit the helmet harder. |
| 6 | Closed | 2.0 | 27.0 | Mouth and nose hit visor lightly. |
| 7 | Open | 2.0 | * | Chin hit helmet. |
| 8 | Closed | 2.5 | * | Chin hit the helmet hard, jammed jaw bone at right ear. |

* G recording instrument malfunctioned.

## LEAK RATE TEST

The protective assembly was put together without the aluminized coverall, containing the parachute harness and the flotation vest, and without the leather boots with their outer cover. The units assembled were the suit torso, the fabric boots,

the gloves, the neck yoke, and the helmet. The ventilating outlet on the suit torso was blocked and the assembly was then connected to the leak test instrumentation. The leak test instrumentation included a mercury manometer to measure the pressure in the assembly, a flowmeter to measure the air entering the suit, and a mercury manometer to measure the pressure at the flowmeter.

Upon initial inflation there was an extremely high leak rate from the visor attaching mechanism and around the visor itself. The usual procedures would have been to measure the leak rate without attempting any adjustment. However, since this helmet and suit had been used extensively at the Aviation Medical Acceleration Laboratory, Johnsville, Pennsylvania, for various tests in the centrifuge, adjustments to reduce the leak were considered mandatory. The helmet leaks were reduced to one leak of a lower magnitude at the helmet's lower left side visor seal. The leak test results are graphically presented in figure 19. When the assembly was used for a later test, tightening of the visor for the leak test caused the subject great difficulty in raising the visor, or was impossible, without considerable assistance. The standard air used in presenting this data is dry air at 70°F and 14.7 psia.

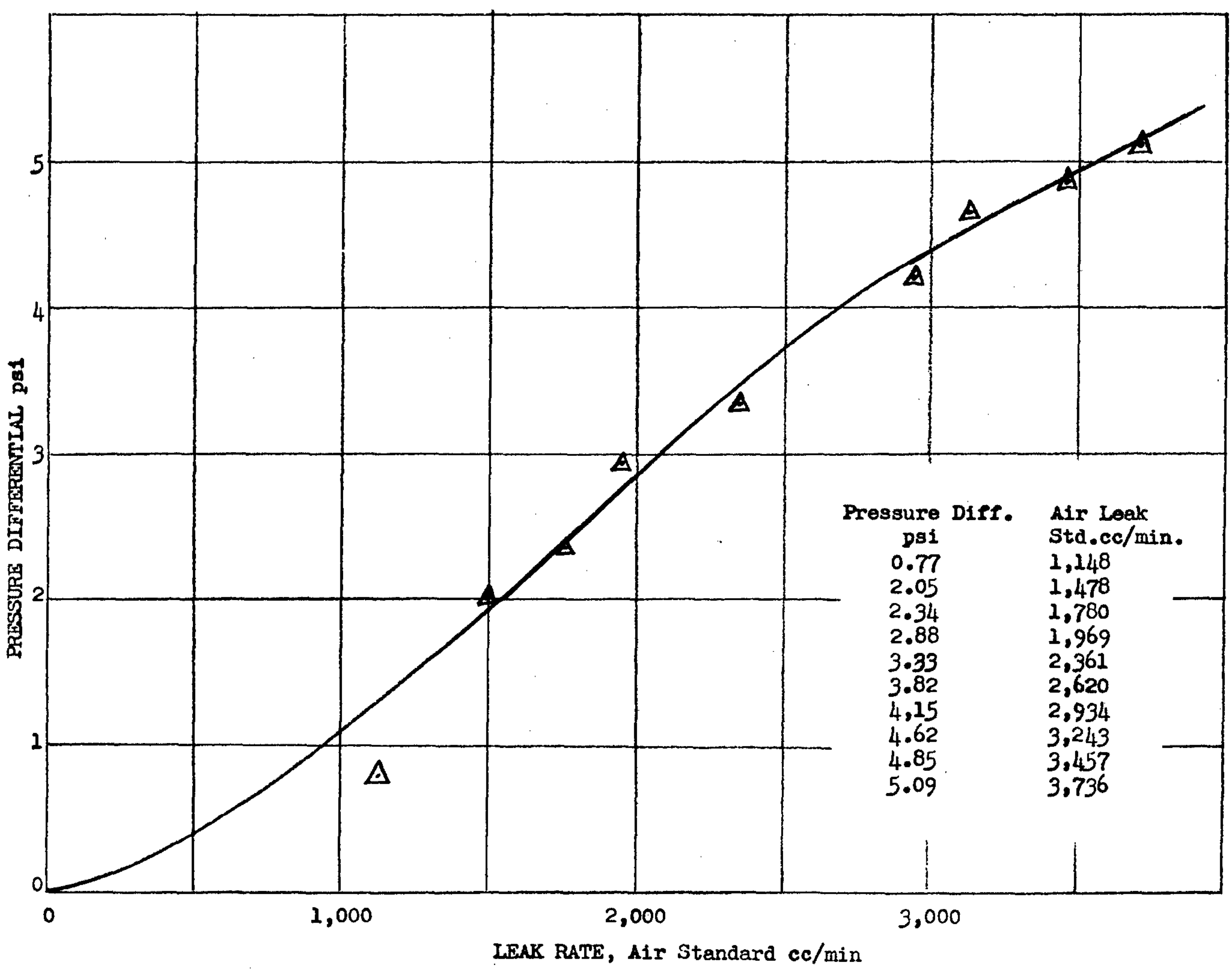



Figure 19. Leak Rate Data

## BACK PRESSURE TEST

The assembly was put together using the same parts used in the Leak Test. The assembly was then connected to the back pressure instrumentation. The instrumentation consisted of mercury manometers at each of the pressure taps shown in figure 21 with a flowmeter immediately upstream from the suit's air inlet opening. The air enters the suit and is distributed through tubes to the wrists, ankles, and helmet. The air washes over the body from the dumping point on the arms and legs to the helmet. The air then enters the return tubing to be exhausted through a port adjacent to the inlet port. Figure 20 depicts the ventilating air flow.

The back pressures found in the suit at the various pressure levels are given in figures 21 and 22. This data represents the performance of the prototype suit with a large leak in the helmet. If this leak could have been eliminated, the back pressure would have tended to increase. The standard air referenced in presenting the back pressure test data is dry air at 70°F and 14.7 psia.

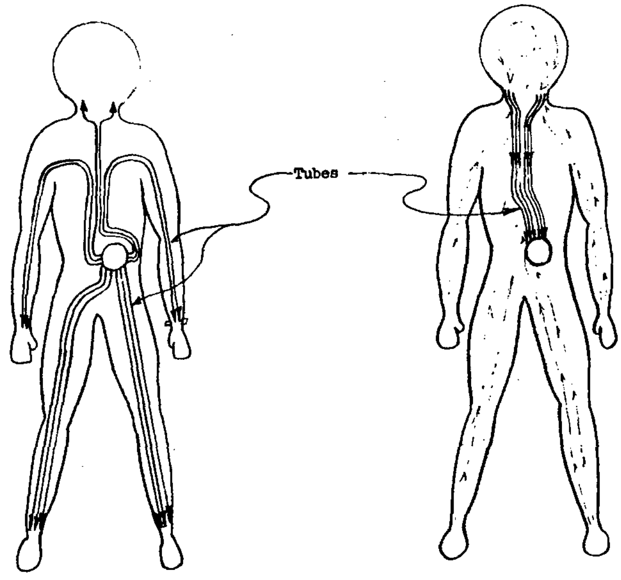
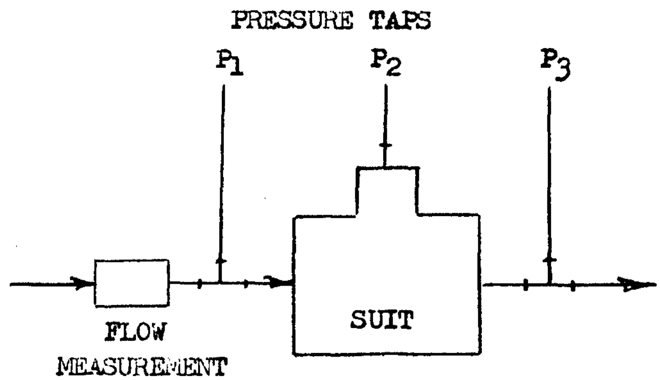



Figure 20. Ventilation Duct System

## CARBON DIOXIDE ACCUMULATION

The $CO_2$ content was determined using a Bendix "time-of-flight" mass spectrometer and a recording oscillograph. Calibration of the instrumentation was accomplished using room air as "zero" and a certified sample of 5.46 % $CO_2$ (equivalent to 40.3 mm Hg partial pressure of $CO_2$ at a barometric pressure of 737 mm Hg).

The assembly was ventilated with air. Each ventilation condition was continued for 3 minutes before recording the $CO_2$ level for 1 minute. The $CO_2$ sampling line was located immediately in front of the mouth and the subject accomplished mouth breathing during the recording period.




$P_1 - P_3 = \Delta P_1$

$P_1 - P_2 = \Delta P_2$

$P_2 - P_3 = \Delta P_3$

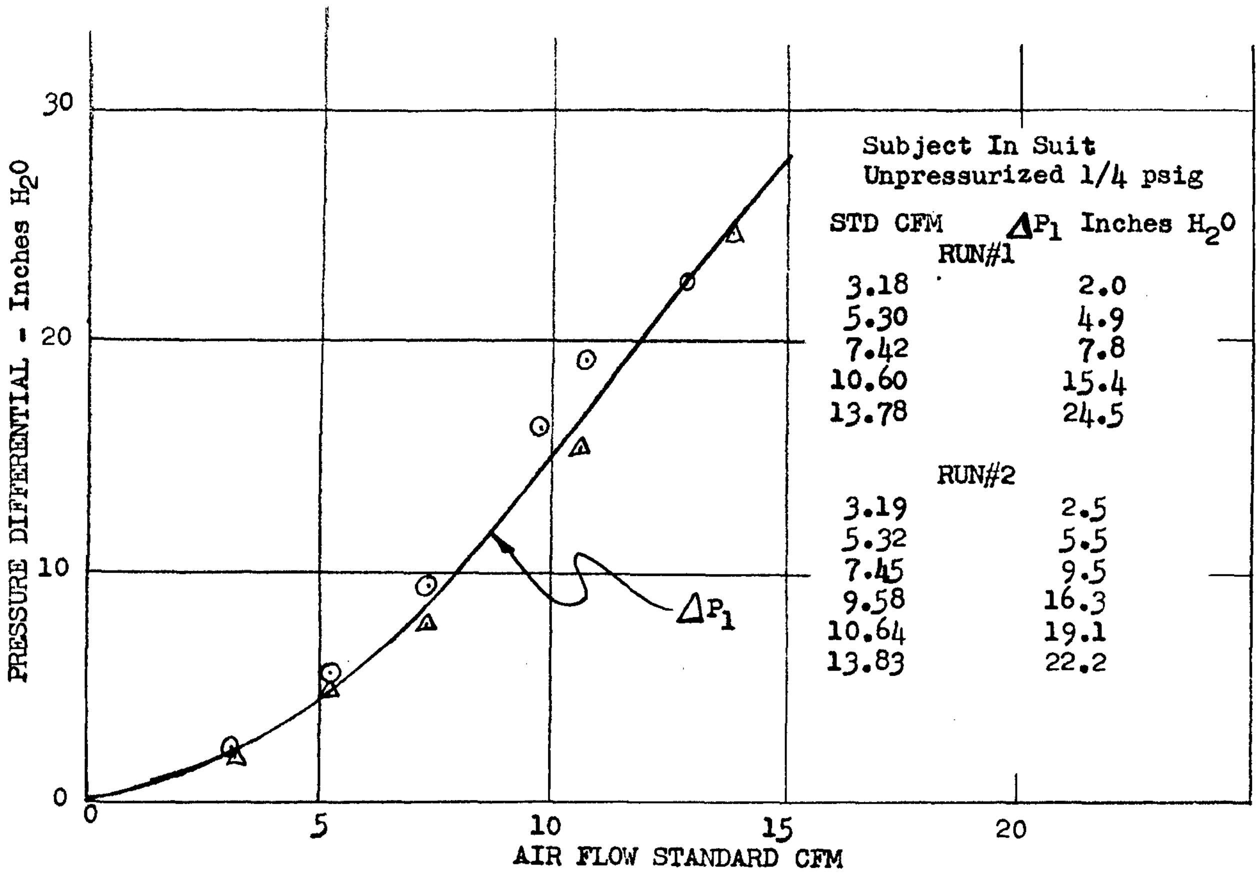



Figure 21. Back Pressure Test Data

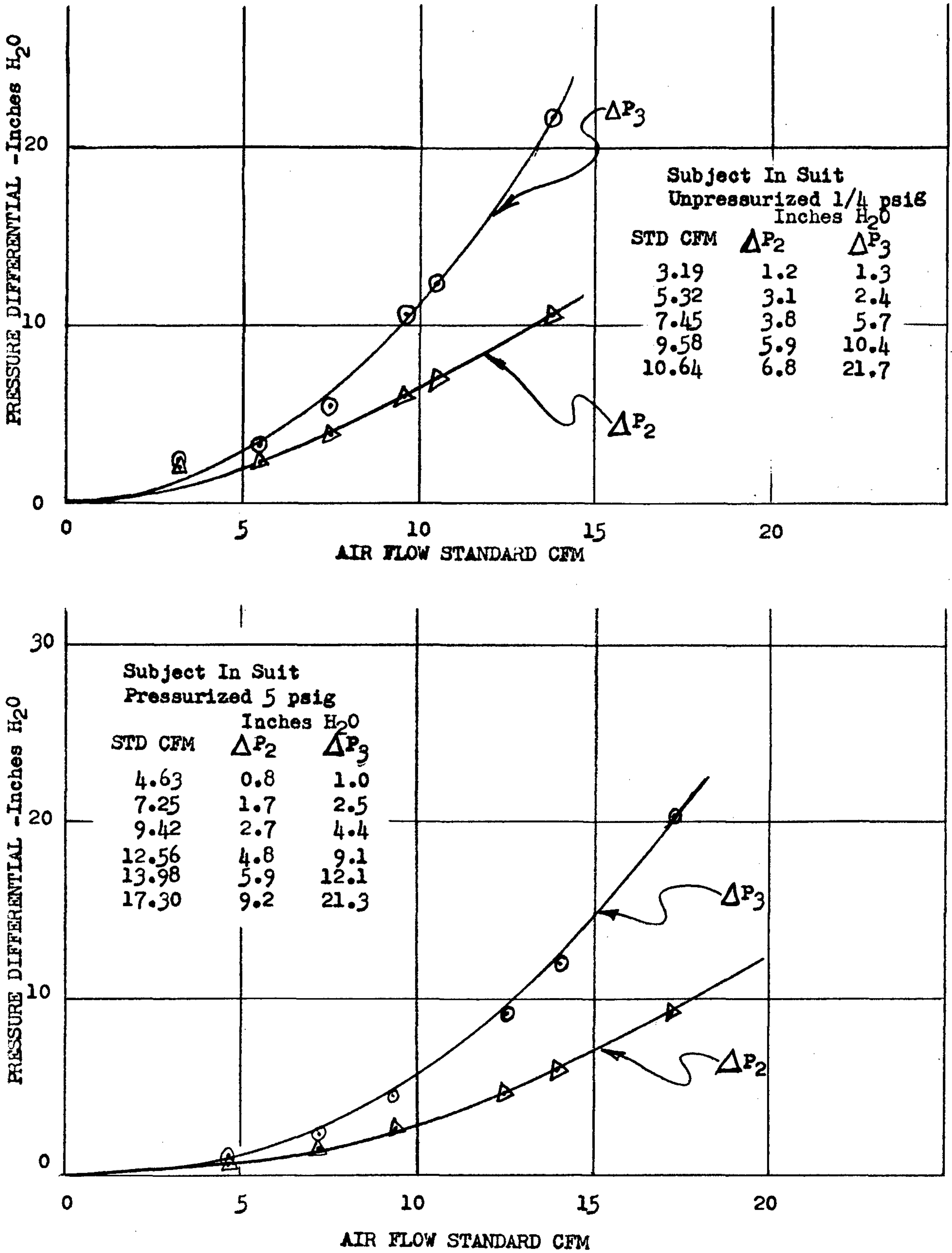



Figure 22. Back Pressure Test Data

Changes in partial pressure of carbon dioxide with ventilation were obtained with the subject sitting at rest.

| Ventilation | | |
|---|---|---|
| Liters/min | Pounds/min | Average Inspired $CO_2$ Partial Pressure - mm Hg |
| 75 | 0.19 | 5.6 |
| 50 | 0.14 | 6.5 |
| 25 | 0.064 | 8.0 |
| 10 | 0.025 | 15.5 |

Ventilation was then reduced to zero and the carbon dioxide partial pressure rose 6.5 mm Hg per minute until the run was terminated at 28 mm Hg.

Following a 10-minute rest period with visor open and adequate ventilation the subject mounted an exercise bicycle and pumped at a moderate work rate about equivalent to walking rapidly. During this period ventilation was maintained at 50 liters/minute. After 6 minutes the partial pressure was 16.8 mm Hg, after 12 minutes it was 22.4 mm Hg and appeared to have stopped rising. The subject stated he was slightly lightheaded, and quite hot. He was breathing deeply and rapidly. Graphic presentations of the above data are set forth in figure 23.

## FLOTATION TEST

The full pressure assembly was subjected to two separate flotation test runs. In the first run the subject, dressed in the full assembly without the buffet helmet and with the visor closed, entered the water from a platform. The visor was opened in a face-up position and after a short flotation period, the subject boarded a one-man liferaft without difficulty. Some water entered through the open visor during this maneuver. The measured weight gain of the assembly was approximately 20 pounds. This increase in weight included water trapped between the layers and moisture absorbed in the material of the assembly.

The life preserver (Mae West) was inflated by actuating the $CO_2$ bottle release mechanism, figure 12. The subject returned to the water from a platform and assumed a face-down attitude. A small amount of water entered the helmet around the visor seal. This leakage was attributed to the fact that the assembly had not been pressurized or vented, thereby positioning the bladder-type seal prior to entry into the water, see figure 2. After a short time in the face-down attitude, a face-up position was assumed, the subject opened the visor to replenish the air, closed it and boarded the one-man liferaft. Boarding the liferaft was easier when the life preserver was inflated than in the unflated state. This was attributed to the fact that the subject in the assembly floated in a higher position relative to the water level with the life preserver inflated. However, in neither condition was it difficult to climb onto the raft. After leaving the water, the suited subject was weighed. The absorbed and entrapped water weighed approximately 20 pounds.

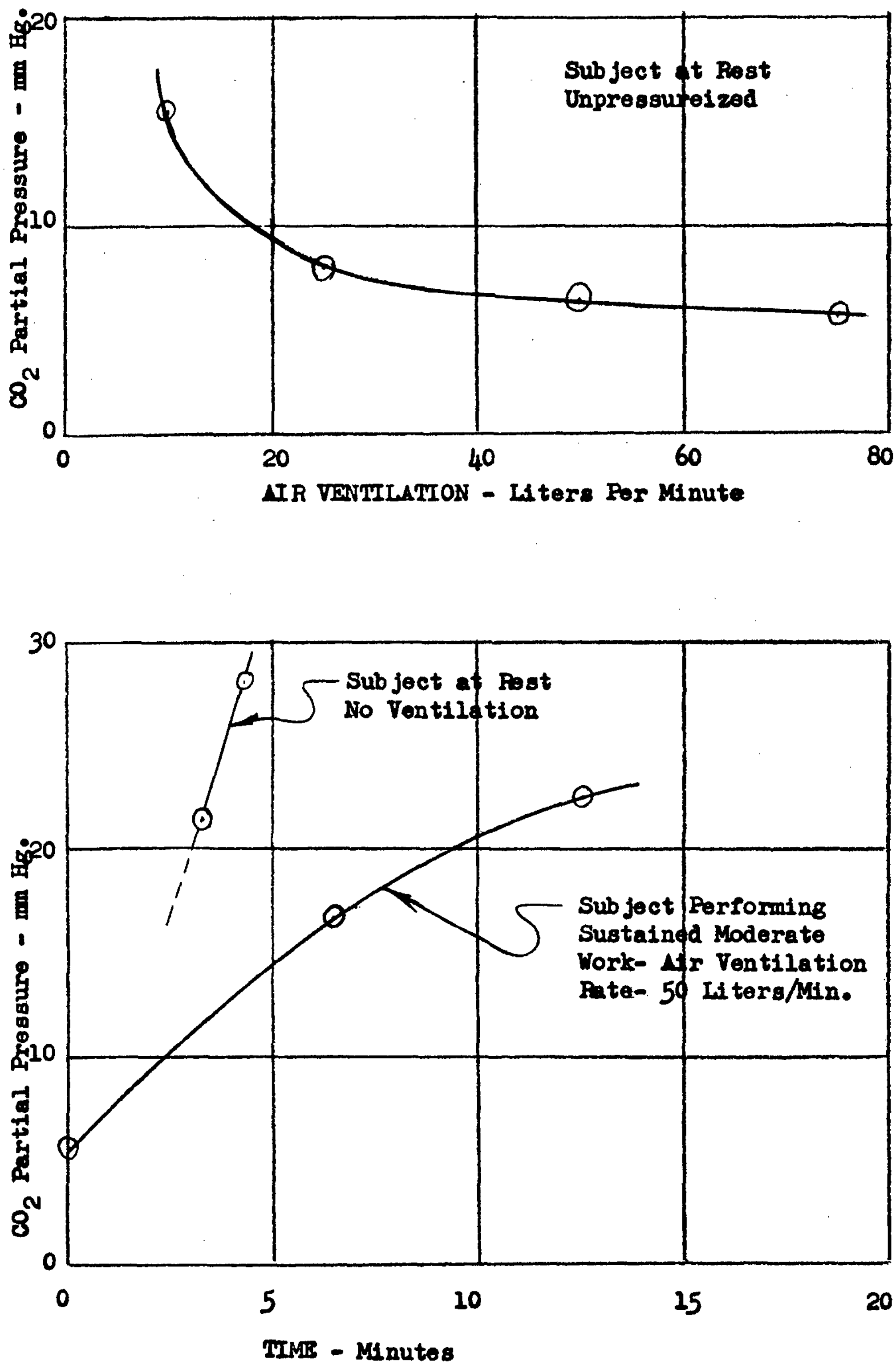



Figure 23. $CO_2$ Accumulation Graph

In the second run the subject, dressed in the complete assembly without the buffet helmet and with the visor closed, entered the water from the edge of the pool. The visor was opened and water was allowed to enter the helmet so as to fill the bladder. When the suit was filled it was necessary for the subject to tread water rather vigorously to keep his head out of water. Boarding a one-man liferaft was executed without difficulty. The flotation vest was inflated by triggering the $CO_2$ bottle. The vest appeared to be soft, indicating that a full charge of $CO_2$ had not entered the vest. The location of the inflated sections of the vest tended to throw the subject forward into the water when he assumed a limp (dead man) attitude. With the visor open for air, the subject's face was near the water surface or under it. When removed from the water the suited subject was weighed. The weight gain, including water to fill the bladder, water trapped in the layers of material, and water absorbed by the material, was approximately 30 pounds.

## ALTITUDE TEST

The prototype suit did not contain an aneroid control, therefore, the only feature to be tested at altitude was the effect of reduced pressure on the materials in the assembly. During the ascent to altitude the buffet helmet began to expand and continued to expand to approximately 25,000 feet. The expansion caused the buffet helmet to become very tight around the subject's head in line with his forehead. He also experienced some discomfort in the area about his ears. Upon descent to ground level the helmet again felt comfortable. The other parts of the assembly did not exhibit any particular reaction to the reduced pressure of altitude.

## HELMET ASSEMBLY ATTENUATION TESTS

Tests of sound attenuation at threshold of the Dyna-Soar full pressure helmet and suit assembly were run first on two subjects, two repeat measurements each. Additional runs were made in an effort to determine the degree to which the attenuation results were affected by masking noise emanating from the blower system. This constitutes a very limited survey and is not sufficient information from which to draw conclusions as to the exact amount of noise exclusion to be afforded the average wearer of the suit. However, the data are sufficient to indicate the need for more extensive tests at such time as the suit and helmet can be made available.

Figure 24 presents the data for one individual when corrected for blower noise. Attenuation for the visor-open condition is similar to that afforded by the same headset assembly without the helmet and is more than adequate to provide reduction of the noise anticipated for conditions when the visor would be open. Closing the visor considerably increases the attenuation throughout the frequency range. If these figures prove to be representative, there should be no difficulty in either maintaining communications or from hearing loss during any phase of the missions.

The data plotted for 2000 cps (2kc) under each condition indicate a slight rise in the curve with visor open and may or may not be significant. It possibly is a function of the Clark earcups only, as similar data are found with this cup when not mounted in a helmet. However, the pronounced peak (29 db rise) with visor closed suggests strongly that a resonance condition exists in this frequency range. The data obtained by Armour Research in a subcontract to Western Electro-Acoustic Laboratory, and reported as Appendix 6 of the final report under Contract AF 33(616)-3710, February 1959, showed very clearly the tendency for a spherical helmet shell of similar dimensions to resonate in the 1200-2400 cps octave band. The insertion of absorbing material helped, but did not completely damp the resonance.

Additional tests would be necessary to determine the extent of this apparent resonance and the effectiveness of various practical damping measures. The reasons for this are as follows:

1. If the resonance is spread over the major portion of the 1200-2400 cps frequency band, the speech interference potential is far greater than would be indicated by the overall attenuation curve.

2. If the resonance is broad or is confined to a narrow band around 2000 cps, such pure-tone screams as are generated by many items of life support equipment (blowers, compressors, hydraulic pumps, etc.) could easily fall in the same range and be magnified to an extremely annoying and potentially damaging degree inside the helmet.

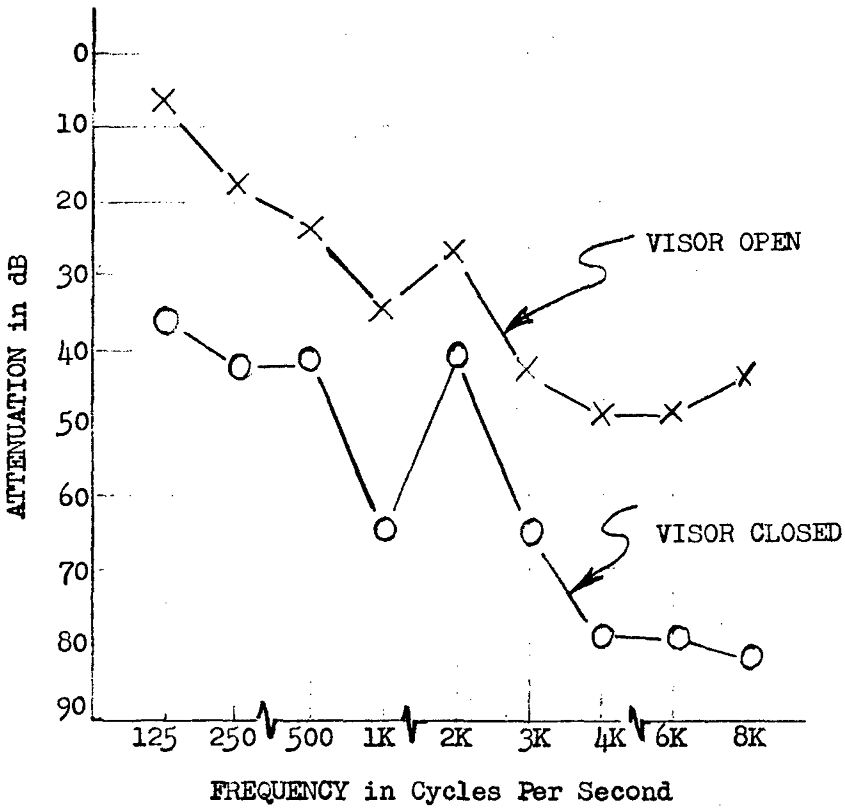



Figure 24. Attenuation Graph

## BIOTHERMAL TESTS

For thermal evaluation of the Dyna-Soar Full Pressure Suit Assembly, three groups of experiments were conducted as shown in table 7. The first group consisted of 19 tests of 1-hour duration when the subject was exposed to three different ambient air temperatures, 160°, 140°, and 120°F, and two different ventilating air conditions, 13 cfm of 75°F and 5 mm Hg water vapor pressure and 8 cfm of 85°F and 5 mm Hg water vapor pressure. These ambient air temperatures and ventilating air conditions were selected to compare physiological responses with those previously obtained with other types of full pressure suits. The tests are listed in table 7. In figures 26, 27 and 28 the experimental results are graphed. The second test group consisted of two tests of 1-hour duration when the subjects were exposed to cold (-25°F) and were ventilated with 13 cfm air of 144°F. The results of these two tests are presented in Figure 29. The third group of tests consisted of six tests from 2-1/2 to 4 hours duration, simulating expected prelaunch conditions. These results are shown in table 8.

TABLE 7

X-20 DYNA-SOAR FULL PRESSURE SUIT
LIST OF BIOTHERMAL EXPERIMENTS

| No. of Tests | Test Group | Hours Duration | Chamber Temp. (Air-Wall) °F | Ventilating Air Flow cfm | Ventilating Air Temp. °F | Ventilating Air Vap.Pr. mm Hg | Comments |
|---|---|---|---|---|---|---|---|
| 4 | | 1 | 160 | 13 | 75 | 5 | Ambient air temperature and |
| 3 | | 1 | 160 | 8 | 85 | 5 | ventilating air conditions |
| 4 | 1 | 1 | 140 | 13 | 75 | 5 | selected for the purpose of |
| 3 | | 1 | 140 | 8 | 85 | 5 | comparison of results with |
| 2 | | 1 | 120 | 13 | 75 | 5 | those obtained with other |
| 3 | | 1 | 120 | 8 | 85 | 5 | types of full pressure suits. |
| 2 | 2 | 1 | -24 | 13 | 144 | | Cold Exposure |
| 1 | | 2.5 | 90 | 3.3 | 70 | dry | Simulating pre-launch |
| 1 | | 3.5 | 90 | 6.5 | 70 | dry | conditions |
| 1 | 3 | 3.5 | 90 | 10.0 | 70 | dry | |
| 1 | | 4 | 90 | 6.5 | 50 | | |
| 1 | | 4 | 70 | 3.3 | 50 | | |
| 1 | | 4 | 70 | 6.5 | 70 | | |
| 27 | Total Number of Tests | | | | | | |

Table 7. List of Biothermal Experiments

All experiments were conducted in the All-Weather Room of the Biothermal Section with two young healthy subjects experienced in thermal test procedures. Steady-state environmental conditions at ground level were maintained and subjects were sitting-resting, figure 25. Total sweat loss was obtained by weighing the nude subject before and after the test. Sweat evaporated during the test was detected by weighing the clothed subject before and after testing. Figure 26 shows the relationship between sweat produced and sweat evaporated at different ambient air

temperatures and ventilation conditions. Skin temperature (taken at 17 points), rectal temperature, and heart rate were measured and recorded continuously throughout the tests. The index of strain was calculated from the above measured parameters, and its relationship to ambient air temperature and two ventilating air flows of different temperatures is shown in figure 27. The actual body heat storage ($Q_s$) was computed from the equation

$$Q_s = \frac{0.831 \times t_b \times \text{weight}}{\text{body surface area}} \quad (\text{kgcal/m}^2)$$

where 0.831 = specific heat of body mass (kcal/kg/°C)

$t_b$ = change in body temperature (°C)

weight in kg

body surface area in $m^2$

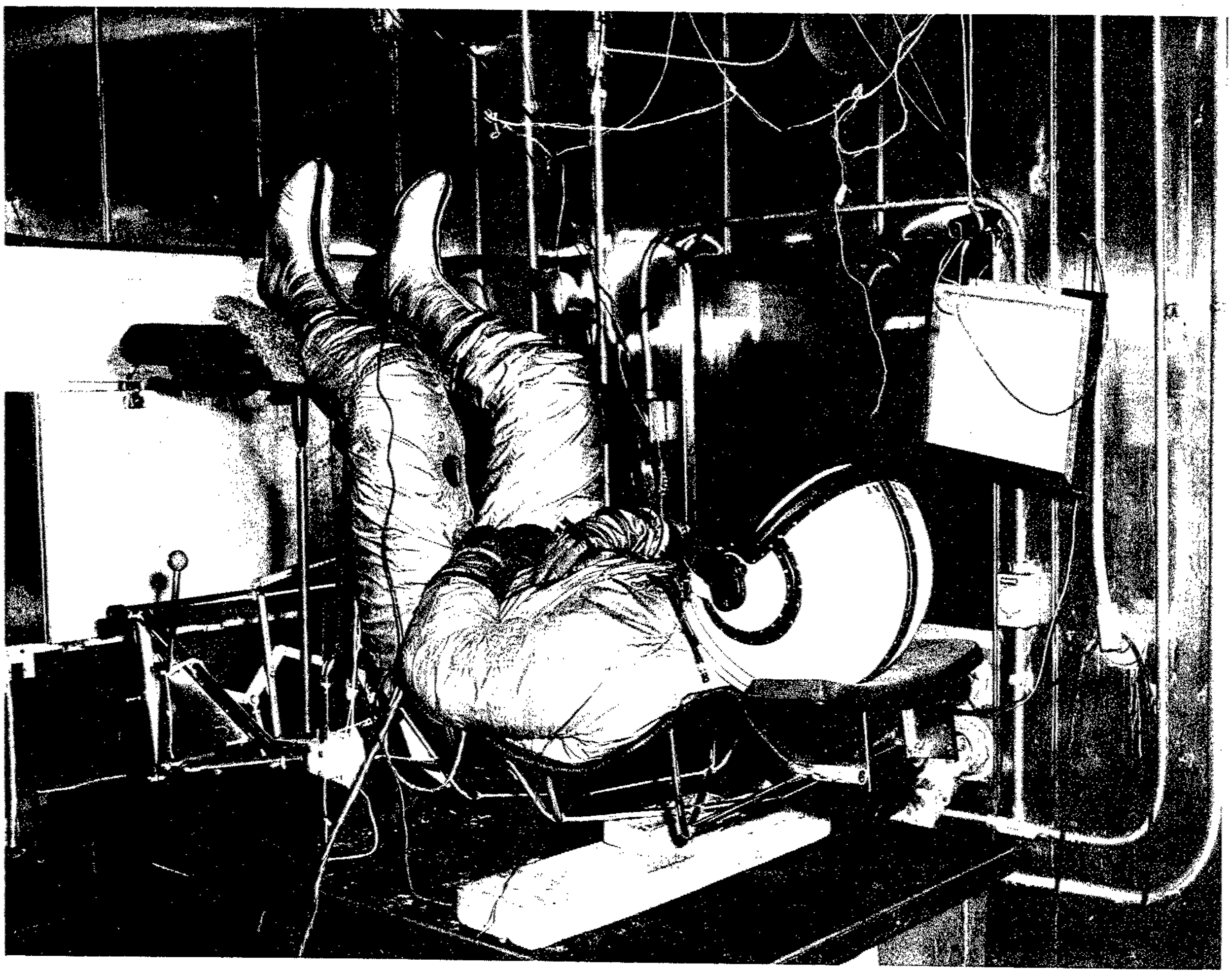


Figure 25. Biothermal - Subject in Chamber

Comparison of body heat storage rates obtained with this equation is most valid when initial body temperatures are equivalent. Therefore, for valid comparison the body temperature had to be adjusted at the beginning of each test to a level equivalent for all tests. This was done in the evaluation of the test results by shifting the beginning of each test to that point where a mean comfort body temperature of 94.2°F was obtained. Difference between this temperature and those obtained after an hour test duration were used for computing body heat storage rates. These adjusted body heat storage rates were then used for comparative purposes. The body heat storage rates measured at different chamber temperatures and ventilation conditions are shown in figure 28. Line of "unimpaired performance" has been added in figure 28 to allow prediction of exposure time for unimpaired performance.

The heat exposure tests (first group) indicate superiority with respect to protection against heat. This superiority is primarily due to the added insulation of the suit, which reduces conducive-convective heat transfer from the suited man to the environment.

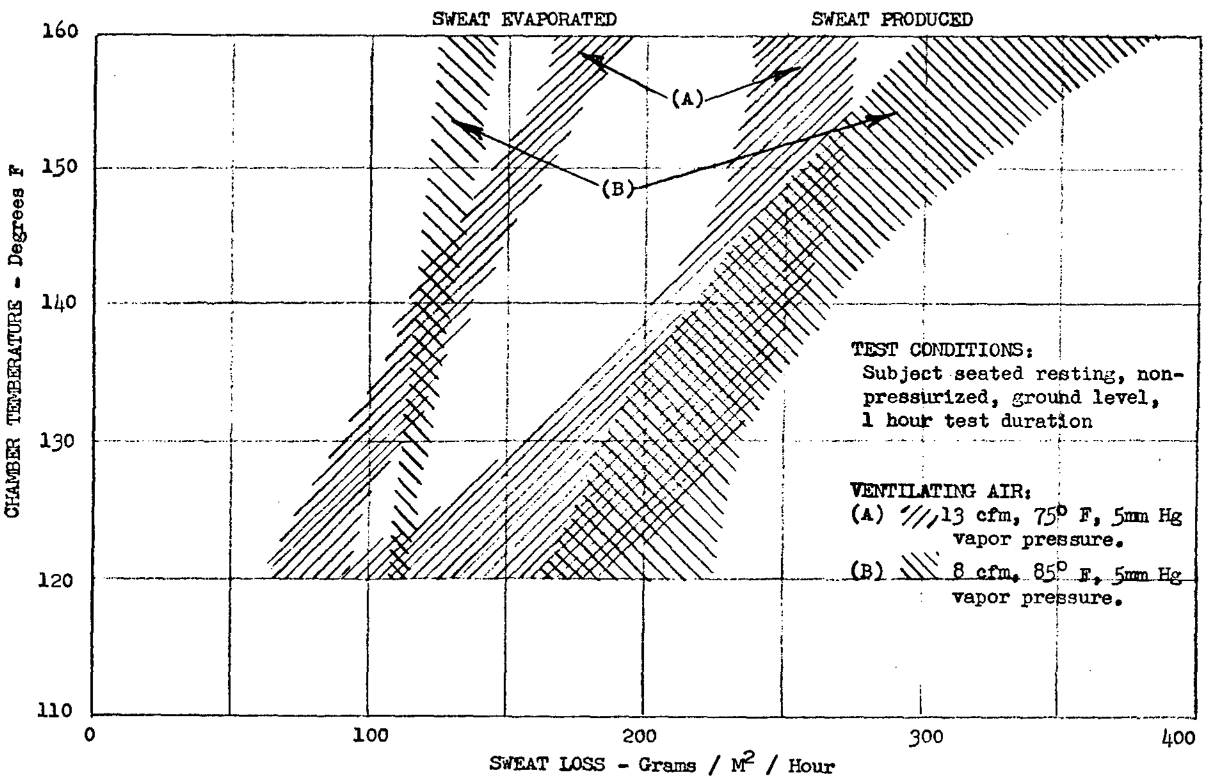



Figure 26. Biothermal - Sweat Production and Evaporation

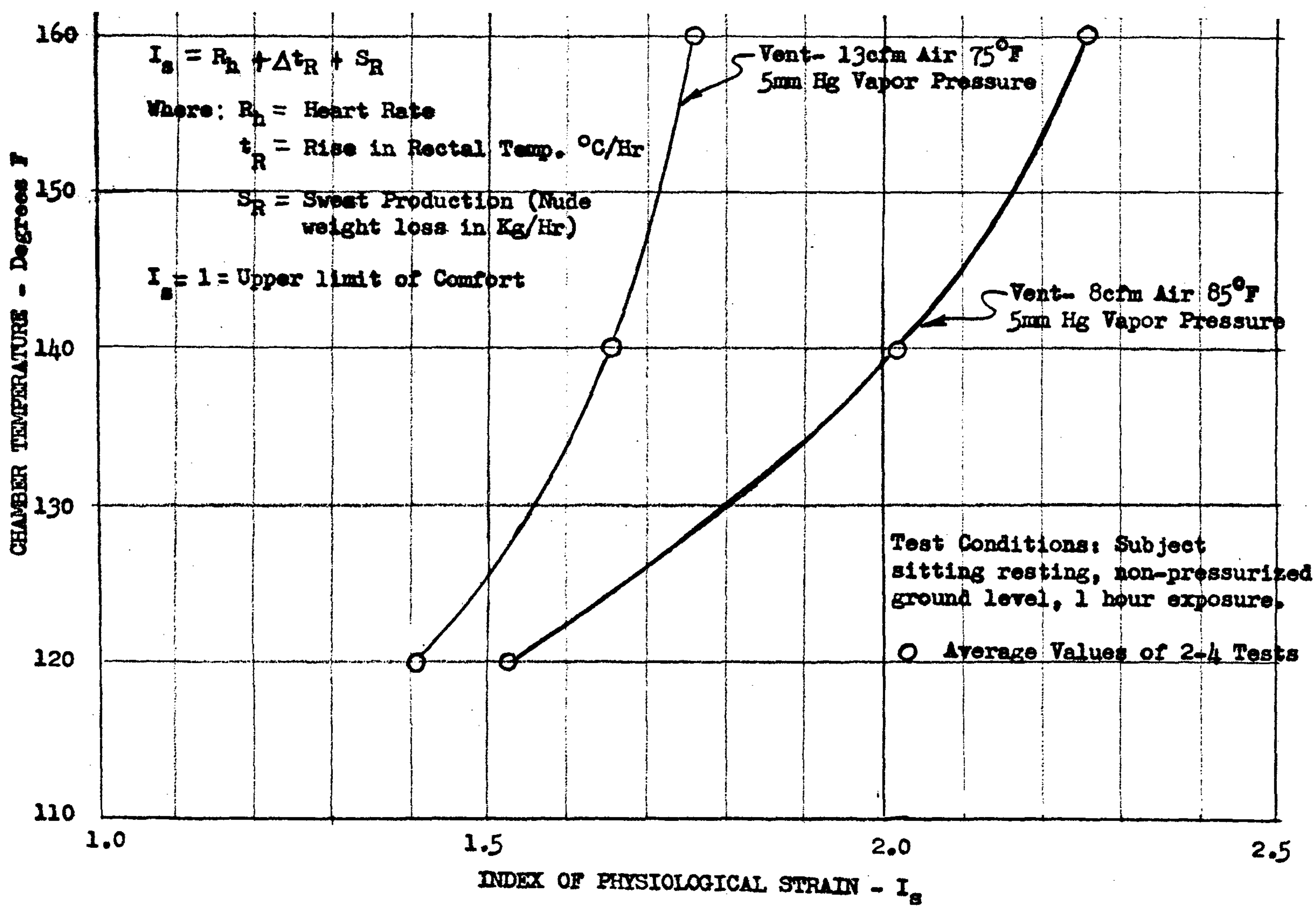



Figure 27. Biothermal - Strain Index

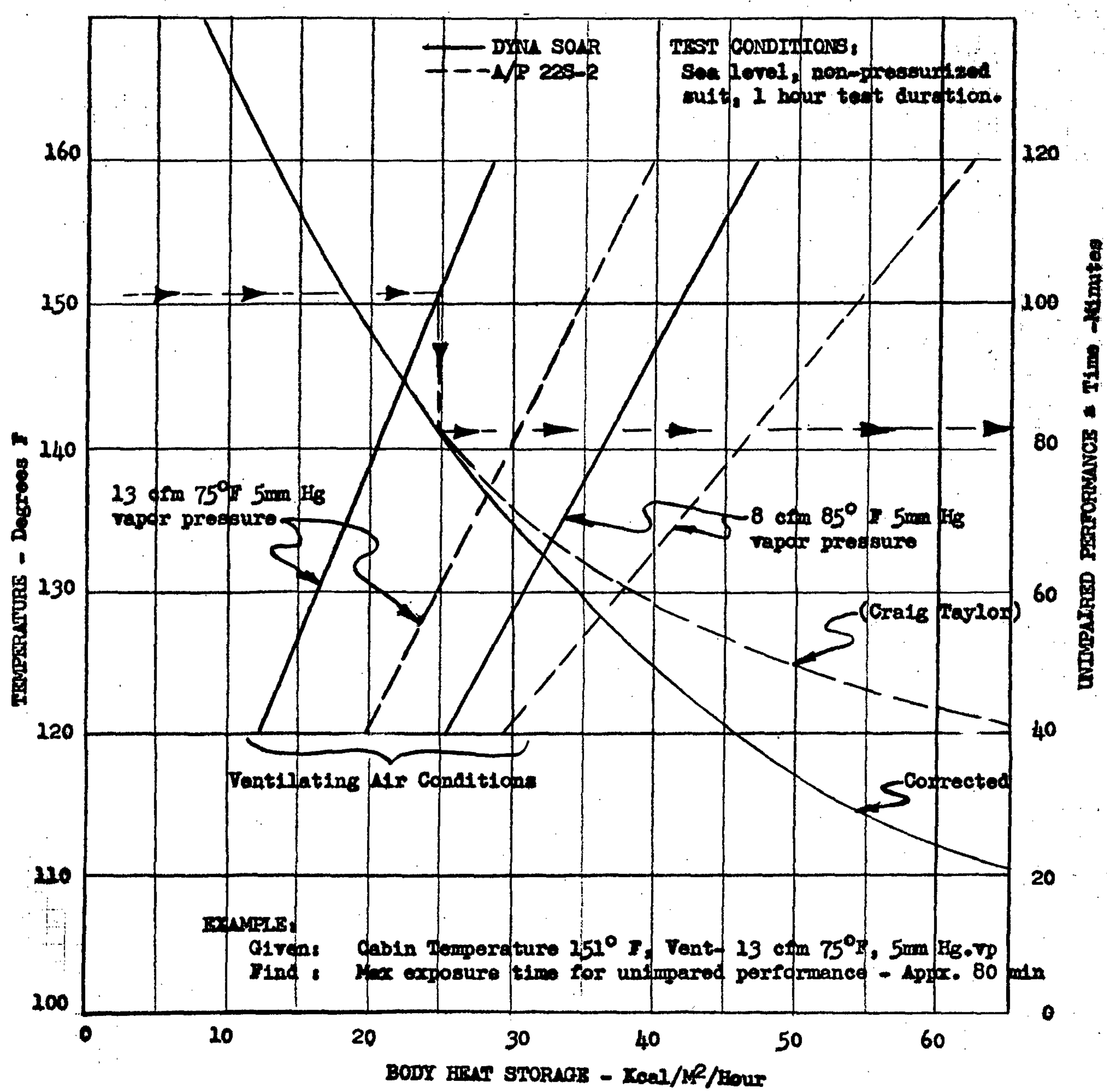



Figure 28. Biothermal - Heat Storage Comparison

The cold exposure tests show that, even at the high ventilating air temperature (144°F) and flow of 13 cfm, fingers and hands cool very rapidly. By movement of finger, hands, and arms some ventilation of the gloves could be obtained. The subjects felt pain in their fingers and hands after 1/2 hour exposure. Fog inside the visor was observed after 7 minutes of exposure. After 30 minutes ice formed inside the helmet visor.

The tests simulating prelaunch conditions indicated that to prevent accumulation of sweat in the suit, the cabin temperature should be kept at 70°F. A ventilating air flow of 6.5 cfm of 70°F (dry) is adequate to maintain crew comfort and prevent sweat accumulation. Closing of the zippers at the boots caused pressure spots. No Dyna-Soar seat was available, but the posture of the pilot was simulated. Therefore, no comments on actual seat comfort can be made.

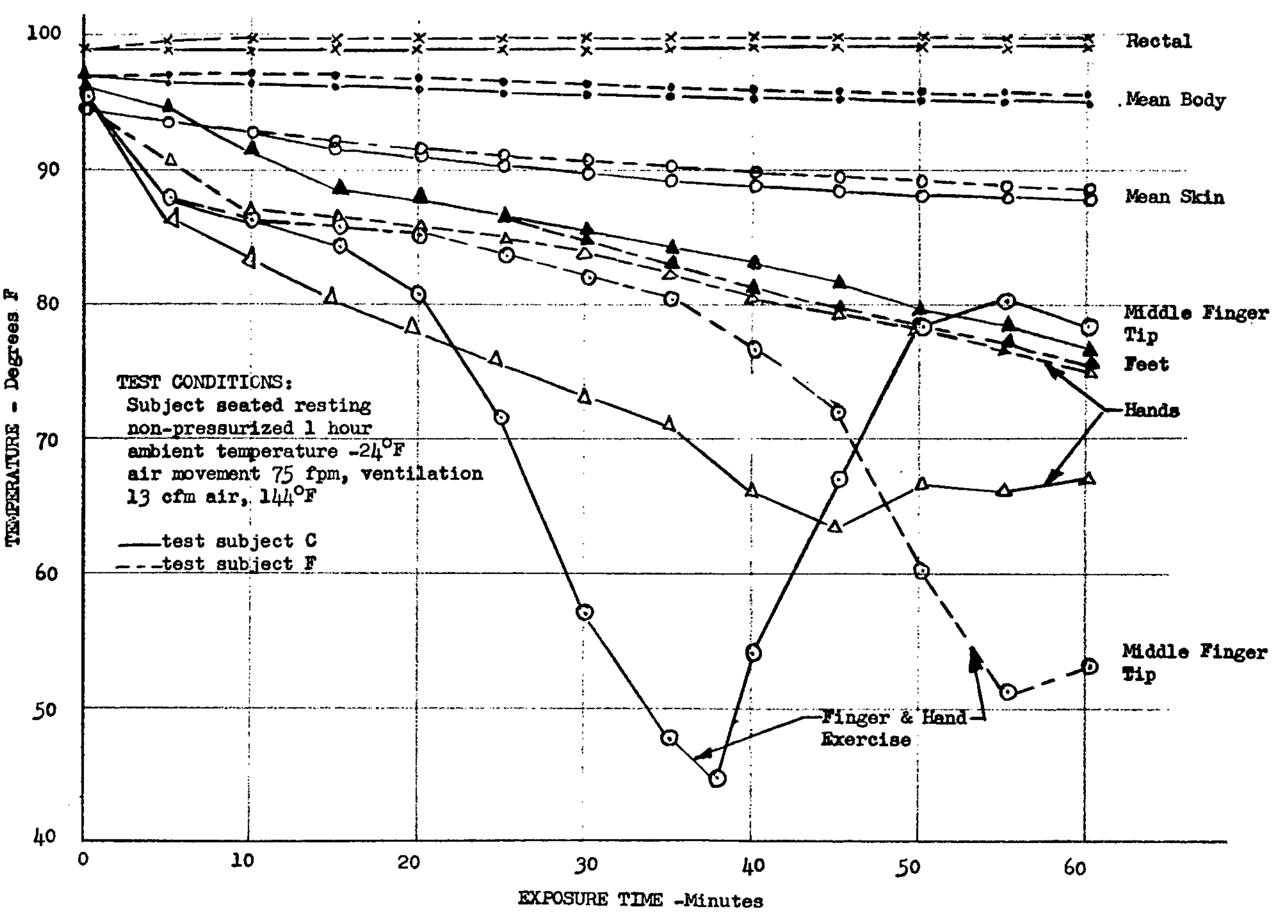



Figure 29. Biothermal - Cold Exposure Test

TABLE 8

X-20 DYNA-SOAR FULL PRESSURE SUIT
PRELAUNCH BIOTHERMAL SIMULATION

| Test Number | Duration of Tests | Chamber Air-Wall Temp. °F | Vent. Air Flow cfm | Vent. Air Temp °F | Vent. Air Humidity | Sweat Grams Prod. | Sweat Grams Evap. | Sweat Grams Accumu-lated in Suit | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 hrs 27 mins | 90 | 3.3 | 70 | dry | 420 | 240 | 180 | Visor open*, body heat level (BHL) elevated at 18.9 Kcal/m$^2$ after 30 min remained balance at this level to end of test. |
| 2 | 3 hrs 30 mins | 90 | 6.5 | 70 | dry | 548 | 432 | 116 | Visor open for 90 min BHL elevated at 13.7 Kcal/m$^2$ after 1 hr. then visor closed for 25 min. BHL decreased to 6.8 Kcal. |
| 3 | 3 hrs 30 mins | 90 | 10 | 70 | dry | 372 | 304 | 68 | Visor open for 2 hrs then closed. BHL slightly decreased below control level. |
| 4 | 4 hrs | 90 | 6.5 | 50 | dry | 408 | 208 | 128 | Back pressure of suit maintained at 29 mm Hg (visor closed). After 80 min body heat level increased at 9.2 Kcal/m$^2$ remains balanced at this level to the end of test. |
| 5 | 4 hrs | 70 | 3.3 | 50 | dry | 193 | 109 | 84 | Visor open for whole test duration. Slightly decreased body heat level but large cold spot at chest area. |
| 6 | 4 hrs | 70 | 6.5 | 70 | dry | 237 | 237 | - | Visor open for whole test duration. Slight decrease of body heat level. |

*Visor open: ventilation air escapes from helmet.
Visor closed: ventilating air escapes from suit outlet (efficiency of ventilation improved)

## SUMMARY OF MALFUNCTIONS

The first failure was a leak in the helmet. The leak was attributed to weakening of the visor spring, which is a part of the closing mechanism. The loss of power in the spring permitted the visor to ride against the sealing bladder around the periphery of the visor opening as shown in figure 2. With continued usage the bladder ruptured, the release mechanism failed to initiate release and as a result the helmet was not usable. The helmet was repaired and tests were continued.

The second failure was the deterioration or rotting of the neoprene rubber bladder in the glove. During one of the biothermal runs the subject felt excessive cooling on ventilation of the left hand. At the end of the run a rupture was found in the glove bladder. As the subject removed his hand, the tear became more pronounced as shown in figure 30. After the initial break the bladder seemed to be extremely fragile and continued tearing without appreciable force being applied. The glove was repaired by installing a new bladder and the tests were continued.

All other limitations or failures in the performance of the assembly are attributed to design limitations rather than the failure of a part to continuously perform the same function.

Figure 30. Glove Bladder Failure